24 Is not animal motion performed by the vibrations of the medium excited in the brain by the power of the will - ?

We turn now to the last group of 7 queries

25.) Deals with double refraction -
Are there not other ~~prop~~ original properties of light besides those already described

26) Have not the rays of light several sides?

27. Are not all hypotheses erroneous which explain modifications of light by modification of the rays - (reference to Hooke)

28 Are not all hypotheses erroneous in which light is supposed to consist in pression or motion propagated thro' a fluid medium

a) rectilinear propagation not explained

b) cannot explain polarization phenomena.

c) cannot explain Fits of easy reflexion, easy transmission.

(later of course all this was explained by Fresnel with wave theory of light.)

N. is attacking Huygens, Treatise on Light (1690) (Traité de la lumière)

p.369 N. proceeds to attack the idea of a medium, argues for existence of God — famous passage on

e.g. 'The main business of natural philosophy is to argue from phenomena without feigning hypotheses, and to deduce causes from effects' till we come to the very first cause, which certainly is not mechanical" ...

29 Are not the rays of light very small bodies emitted from shining substances?

31. Have not the small particles of bodies certain powers, virtues or forces by which they act at a distance not only upon the rays of light, but also upon one another for producing a great part of the phenomena of nature

This famous final query really outlines an atomic theory of matter with interatomic forces — very influential in 18th C development in chemical elements and later in Laplacian field of theoretical physics dealing with elasticity, capillarity etc. Also influenced electrical and magnetic theories of action-at-a-distance

p. 400

"All these things being considered it seems probable to me that God in the beginning formed Matter in Solid, Massy, hard, impenetrable, moveable particles of such sizes & figures, & with such other properties, and in such proportion to space, as most conduced to the End for which he formed them.

— — —

These particles are moved by certain active Principles, such as is that of Gravity — —

These Principles I consider not as occult Qualities . . . but as general Laws of Nature . . . their truth appearing to us by phenomena though their causes be not yet discovered".

p. 402 Inconsiderable irregularities may arise "from mutual actions of comets & planets and which will be apt to increase, till this System wants a reformation".

— Argt. for continued intervention of God in his universe.

Cf problem of stability of the solar system -

p. 404 God, could ~~no~~ vary the laws of Nature and make worlds of several sorts in several parts of the Universe. At least, I see nothing of contradiction in all this".

Concludes with exposition of method of analysis (from ~~[illegible]~~ compounds to ingredients) and then synthesis to explain phenomena proceeding from the analysis.

HISTORY OF SCIENCE II

The course is concerned with the history of Mathematics and Physics in the 19th Century.

Mathematics ⟶ Donald.

Physics Three principal themes will be discussed, Energy, Atom and Field

these will lead to a study of the development of thermodynamics, the kinetic theory of gases, and the theory of the electromagnetic field. The main emphasis will be on the period 1820 – 1870.

Relevant primary source material is reprinted in the following:

S. Brush: Kinetic Theory I, The Nature of Gases and Heat

E. Mendoza (ed.): Reflections on the Motive Power of Fire

T.A. Hirst (ed): The Mechanical Theory of Heat. (Clausius papers)

J. Tyndall and W. Francis (eds.): Scientific Memoirs: Natural Philosophy

~~B.~~ J.C. Maxwell: Scientific papers.

M. Faraday: Experimental Researches in Electricity

Lord Kelvin: Mathematical and Physical Papers

J.P. Joule: Scientific Papers

W.F. Magie: A Source Book in Physics

R. Lindsay (ed.): Energy: Historical Development of the Concept

R. Lindsay (ed.): Early Concepts of Energy in Atomic Physics

Background Reading.

D. Cardwell: From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age.

C. Gillispie: The Edge of Objectivity, Chapters 9 and 10.

M. Hesse: Forces and Fields.

L. Pearce Williams: The Origins of Field Theory

W. Berkson: Fields of Force

S. Brush: The Kind of Motion we Call Heat (especially vol 1)

See also
T. Kuhn: Energy Conservation as an Example of Simultaneous Discovery (1959)
(reprinted in The Essential Tension 1977)

Y. Elkana : The Discovery of the Conservation of Energy.

C. Everitt : James Clerk Maxwell: Physicist and Natural Philosopher.

L. Königsberger : H. von. Helmholtz.

S.P. Thompson : Life of Lord Kelvin

J. Tyndall : Faraday as a Discoverer

L. Pearce Williams : Michael Faraday: A Biography.

E.T. Whittaker : History of the Theories of ~~Aether~~ Aether and Electricity.

K. Schaffner : Nineteenth-Century ~~Aethe~~ Aether Theories.

J. Kestin (ed) The 2nd law of Thermodynamics

A. Tricker : The Contribution of Faraday and Maxwell to Electrical Science

History II

2 views on 19th c. physics

1) Culmination of Newtonian mechanical world view

2.) Retreat from Newtonianism

We distinguish 3 components in Newtonianism

a) material substances (corpuscles)
b) motions of corpuscles
c) Forces between corpuscles - at a distance

Contrast Cartesianism

a) Material substance (continuum with particles as different states of aggregation of the continuum)
b) motion
c) 'contact' forces only.

Cartesianism leads to effluvial theories of electrical interaction (but these were thought of as streams of particles)

(cf Abbé Nollet, LeSage Theory of gravitation)

But contrast late 18th c imponderables 'electric, magnetic, caloric and optical fluids' which are regarded as corpuscular in nature (following Newton, Boyle etc — cf Gassendi's revival of atomism of Democritus, Lucretius, Epicurus etc)

these imponderable particles acted on one another at a distance as did the corpuscles of ponderable matter.
This was the general view of the French molecular school who explained continuum mechanics (Euler, Bernoulli) and capillarity in terms of forces between corpuscles.

Main exponents of this school are Laplace, Poisson, Navier, Cauchy, St Venant, Ampère.
Contrast the positivist phenomenological school of French mathematical physics represented by Fourier

True continuum view held by Stokes in England and Helmholtz in Germany. Helmholtz contrasts two aspects of reality corpuscles & continua — waves, particles as we might say.

Several themes emerge in 19th C physics

1) Corpuscular theory of light → (continuum) wave theory light
2.) Caloric (continuum) theory of heat → Kinetic theory of heat.
   ↳ Conservation of Energy → Thermodynamics
3.) Action-at-distance in electromagnetism replaced by continuum field view of interaction.
4.) Several views about fields
   a) Faraday — field = lines of force
      matter developed of Boscovich point atoms

2) Maxwell reconsiders mechanical views of ether but regards it probably as ultimately conjunction in Nature itself.

cf Atmospheric Atoms around 1800

material corpuscles surrounded by several atmospheres of imponderable particulate fluids and designed to explain electric, magnetic, optical, thermal or gravitational effects.
Maxwell essentially reduced the imponderable fluids to ~~one~~ the electromagnetic aether ~~but~~ the difficulties in this account → Relativity

N.B. The aether is all-pervading, unlike caloric or electric fluid.

Note Lavoisier abolished phlogiston — 'chemical' substance emitted in combustion, but strongly advocated the caloric theory of heat.

Three main concepts emerge
Atom — Dalton — chemical atom 1808 New System of Chemical Philosophy
→ K.T. gases (not accepted by chemists until Cannizzaro revival of Avogadro (1811) in 18~~60~~58.

~~Kinetic Theory~~

Energy — Naturphilosophie, Schelling, Goethe, Coleridge

L all forms interconvertible
or all energy is at base mechanical
i.e. Kinetic, potential.

Joint Discovery : Kuhn in The Essential Tension.

{Mayer 1842-45
Helmholtz 1847
Joule 1849

~~Field Faraday, Maxwell.~~

Thermodynamics Availability of heat energy for work — steam engine — Watt.

— Sadi Carnot (1824) — Reflections on the Motive Power of Heat.

{Clapeyron
Clausius
Kelvin

Field Faraday ← Oersted (1820)
Maxwell. ~~A~~ Ampère
↓
Action at a distance
↓
Weber
Franz ~~E.~~ Neumann.

~~Reaction~~
e-m. theory of light (~~186~~) (1861)

Josef Loschmidt in 1865 estimated size of molecules.

mean free path (from viscosity) $\rightarrow Nd^2$
Vol of liquid phase $\rightarrow Nd^3$

Hence we can estimate N and d

2×10^{18} (modern value is 2.7×10^{19})

10×10^{-8} cm for air molecule.

d = diam. of molecule
N = no of molecules per cc. at STP
= Loschmidt's No

(cf Avogadro's No = no of molecules per gm molecule.)

K.T. gases — Newton – static model (Principia) 1/r law

1.) Bernoulli 1738

2.) John Herapath 1820

3) Waterston rejected by R.S. 1845
later rediscovered by Rayleigh 1892

4.) Joule. Calculated speed of molecules. ~~1847~~ (after Herapath) 1848
6225 f.p.s., 60°C, 30in mercury

5.) Kronig 1856

6.) Clausius 1857 'of the kind of motion we call heat'
1858 – mean free path.

7.) Maxwell. statistical method (1859) and (1866)
1860, 1867

8.) Boltzmann H-theorem etc, 1868, 1872.

SH Novel prediction viscosity of gas independent of pressure.

Difficulties Specific heats of gases and exact treatment of transport phenomena. – aether not particulate a word outside of SH/S – two ideas of continuous aether – cf Rayleigh–Jeans R.J. Law.
Vortex Atoms Model of ~~Thomson~~ Thomson (Kelvin)

Specific heats vary with temperature
Internal motions should only be handled by QM, internal degrees of freedom become unfrozen only at high temperatures.

Personalities

John Herapath (1790–1868)
1820 paper rejected by Royal Society
Equilibrium condition to equality of mv not mv^2
Published in Annals of Philosophy, later
in Phil Mag. – influenced Joule.
1847 published 2-volume Treatise 'Mathematical
Physics' extending his 1820 work.

John Waterston (1811–1883)

1845 paper rejected by R-S. "The paper is nothing
but nonsense, unfit even for reading before the
Society". rediscovered in Archives of R-S.
by Rayleigh in 1891 > [illegible] with highlight
comments – get $m_1 v_1^2 = m_2 v_2^2$ law - upt
for equilibrium.

James Prescott Joule (1818–1889) 1857 paper in Phil. Mag. was originally
published in 1848 in Memoirs of the Manchester
Literary and Philosophical Society. See also
his lecture 'On Matter, Living Force and Heat'
in Manchester Courier 1847

August Krönig (1822–1879). 1856

paper. 1st account of K.T. after
1st law of thermodynamics had been
established.

Rudolf Clausius (1822–1888) real founder
of K.T. 1857 'On the Kind of Motion
we call Heat' – developed from his

idea or Thermodynamics
– Herapath, Clausius, 1830's
revival of thermodynamics by Clausius (1858)

1858 developed concept of mean free path.

Jones Clerk Maxwell (1831–1879)

of Adams Prize Essay on Saturn's rings

1860 ~~1859~~ paper develops Theory of Transport phenomena, in particular viscosity η

η independent of pressure & $\sqrt{T}$.
Experiment showed $\eta \propto T$ – postulates r^{-5} force law in his 1867 paper

Maxwell also introduced distribution of velocities among molecules in a gas

Radiometer paper sent before his death in 1879.

Ludwig Boltzmann (1844–1906)

extended Maxwell's analysis to derive the general non-equilibrium situation in a gas – the Boltzmann Eq.: H theorem derived in 1872 –

Reversibility, Recurrence paradoxes

~~Loschmidt~~
Loschmidt (1874?)

Zermelo (1896)

J.D. Van der Waals (1837–1923)

developed theory of non-ideal gases
$(P + a/v^2)(V - b) = RT$ in 1873

demonstrated continuity of gas & liquid states — analyses of critical phenomena

of Andrews CO_2 isotherms (1863)

and James Thomson (Kelvin's brother) suggested continuity of state in 1871

Ernst Mach (1838–1916)

rejected K.T. in 1872 onwards.

Major debate between Ostwald and Boltzmann in 1895

cf J.T. Blackmore's book 'Ernst Mach' (1972).

Mach 'gave' up in 1903 & reported to have said 'Now I believe in the existence of atoms!' (Spinthariscope demonstrating α-particle scintillations)
— seeing may be believing?

N.B. Demise of Caloric theory of heat due partly to idea
radiant heat = light = wave motion
(not a substance)

∴ heat not a substance

Also Friction as in cannon boring can produce an unlimited amount of heat -

Vis Viva

mv^2 conserved in elastic collisions shown by C. Huygens (1629–1695) in 1703

(De Motu Corporum ex percussione)

mv^2 given the name Vis Viva by Leibniz in 1695 — contrast with Vis Mortua — P.E.

Leibniz subscribed to a doctrine of general conservation of vis-viva

P.E. is Vis. Viva of the aether — theory rather unclear.

Concept of Energy

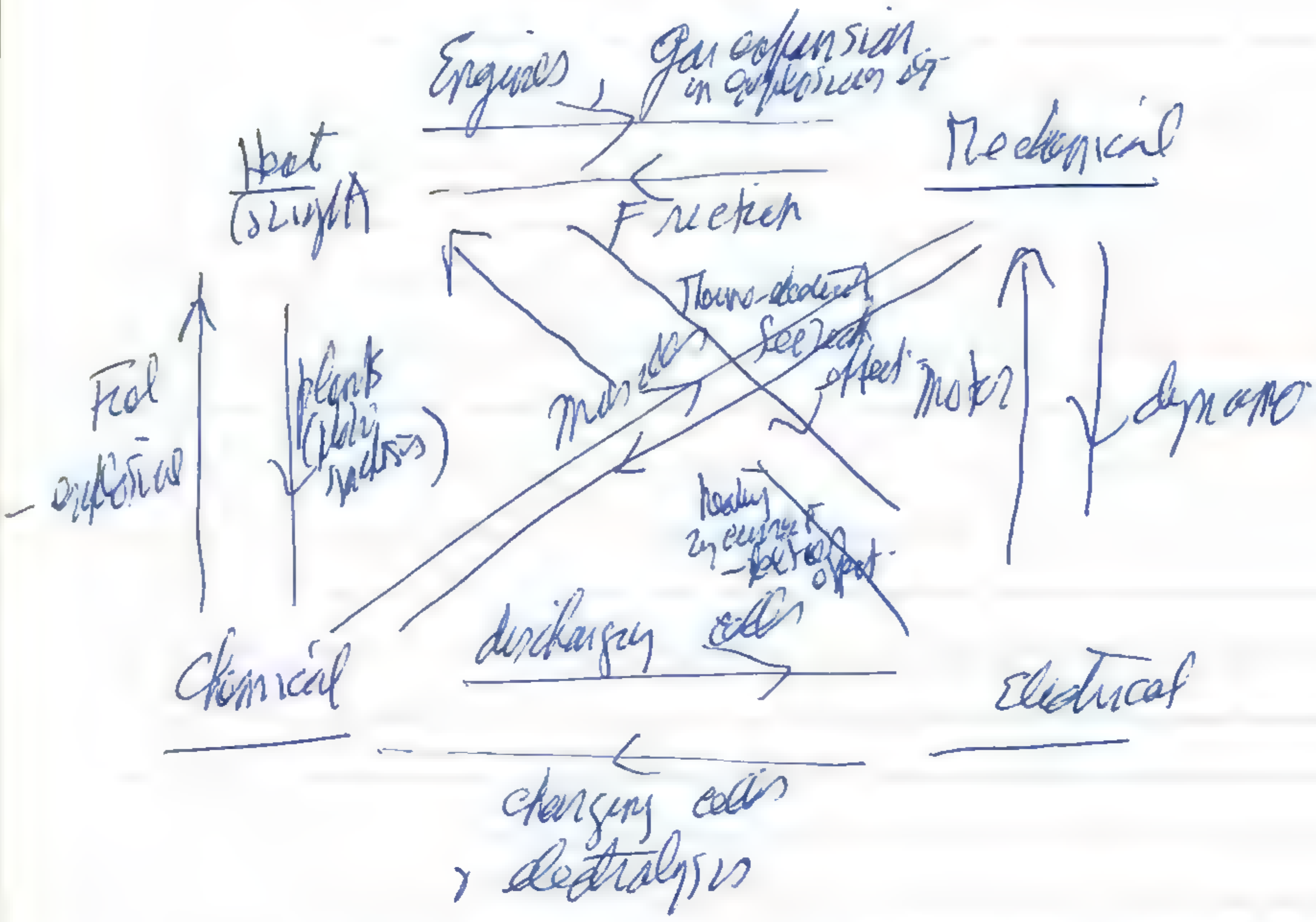
Conservation of Energy

cf. Kuhn The Essential Tension p 66 Energy Conservation as an Example of Simultaneous Discovery

Mayer, Joule, Colding, Helmholtz Faraday (1842–1847) Poncelet

3 Approaches

1.) Conversion Processes



2.) Concern with engines – Development of the steam engine

3.) Natur Philosophie

Limited Conversion heat, work, Holtzmann (1845) Carnot (pub 1832) Séguin 1839, Hirn, 1854.

1837–1844 Vague qualitative notion of a 'single' force differently manifested
Mohr, Grove, Liebig and Faraday

Julius Robert Mayer (1814 – 1878)

Physician, a Kantian, Ship's doctor in tropics – 'venous blood redder in the tropics', less oxygen being used

oxygen = work + heat loss
less in tropics

Concerned with transformation of vital and inorganic forces, Mayer papers 1842, 1845

– Calculated mechanical equivalent of heat from $C_p - C_v = R/J$
gas constant

James Prescott Joule (1818 – 1889)

1843 announces generation of heat with and electrical induction

1845 Paddle wheel expt. – direct conversion mechanical → heat

1847 grand statement in Manchester lecture 'On Matter, Living Force and Heat'.

Hermann von Helmholtz (1821 – 1894) (also trained as a physician)

1847 Erhaltung der Kraft – all energy is ultimately mechanical – Conservation of 'vis viva' for system of particles under central forces

Jean Baptiste
N.B. Joseph Fourier (1768-1830) published his 'Analytical Theory of Heat' in 1822

History of the Steam Engine

1691 Denis Papin suggested condensing steam as method of driving force of the atmospheric pressure

1699 Thomas Savery first working engine on Papin's principle

1712 (maybe 1705?) Thomas Newcomen, first practical engine for pumping water out of mines (in Cornwall etc)

John Smeaton improved in detail

James Watt (1738-1819) introduced separate condenser (patented in 1769 - invented in 1765)

Developed by Woolf, Trevithick, Stephenson etc - steam traction

History of Thermodynamics

Main problem here is availability of energy

Sadi Carnot (1796–1831) 'Reflexions on the Motive Power of Fire' 1824 explained Carnot cycle. Showed no heat engine could be more efficient than a reversible one — a perpetual motion. Efficiency depends only on Temperature drop available. Assumes Caloric theory of heat.

work $\frac{\delta W}{Q} = \frac{T_1 - T_2}{C}$ — Carnot function.

Emile Clapeyron (1799–1864) gave mathematical expression to Carnot's ideas, derived his latent heat equation in 1834

Carnot's work rediscovered & promoted by William Thomson, Lord Kelvin (1824–1907) (like Maxwell 2nd wrangler, published several papers 17 onwards like Maxwell)

In 1848 proposes absolute thermometric scale but still uses Caloric theory. $\frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$

Develops dynamical theory of heat in 1851 'On the Dynamical Theory of Heat', announces

Kelvin's version of 2nd Law

* Work cannot be performed by cooling a substance below the temperature of its surroundings

NB Rankine also enunciated a version of the 2nd Law in 1850

+ ~~B~~ Clausius version of 2nd Law

Heat cannot flow spontaneously from a cold body to a hot water

his version of the 2nd Law*

1854 applies 2nd law to thermoelectricity Seebeck, Peltier, Thomson effects. shows $\oint_{rev} \frac{dQ}{T} = 0$

Also c. 1849 predicts lowering of freezing point of water by pressure. (with his brother James Thomson).

Rudolf Clausius (1822–1888)

enunciates 2nd law. in 1850

† 'On the Moving force of heat and the laws regarding the Nature of Heat', adopts the dynamical theory of heat. Carnot's theorem derived as consequence of 2nd Law†, not an independent notion (cf. 1st Read).

1865 9th memoir Entropy Law

$\int \frac{dQ}{dT} \geq 0$ N.B. term Entropy first coined by Clausius in 1854

Ludwig (1844–1906)

N.B. Boltzmann's noted connection

$S \propto \ln W$ in 1877

Entropy

thermodynamic probability

N.B. Kelvin in 1852 published his paper 'On a Universal Tendency in Nature to the dissipation of Mechanical energy' — cf. Clausius' increase in entropy.

So new view of Nature is not of reversible clockwork but of the gradual running down of irreversible approach to heat death of the universe.

Tension between reversibility of dynamics and irreversibility of thermodynamics resolved (in part) by statistical arguments of Boltzmann.

Note $\frac{Q_1 - Q_2}{Q_1} < \frac{T_1 - T_2}{T_1}$

$\Rightarrow 1 - \frac{Q_2}{Q_1} < 1 - \frac{T_2}{T_1}$

or $\frac{Q_2}{Q_1} > \frac{T_2}{T_1}$ or $\frac{Q_2}{T_2} - \frac{Q_1}{T_1} > 0$

or $\frac{Q_1}{T_1} - \frac{Q_2}{T_2} \leq 0$ for an irreversible change

$S_1 - S_2 \leq 0$

or $S_2 \geq S_1$

Vol I, p.16

At first Faraday thought magnetic field produces electrotonic state in wire (identified by Maxwell with the vector potential) — changing field produces change in the electrotonic state which we interpret as current.

I, p.124 But phenomena of unipolar induction suggested to Faraday a model in terms of cutting lines of force rather
I, p.66 than changes in the electrotonic state.

cf. I, p.16 Faraday also thought electrotonic state involved in electrostatic induction.
'Whilst the wire is subject to either volta-electric or magneto-electric induction, it appears to be in a peculiar state'.

19th Century Field Theory

1. Wave Theory of light developed by Thomas Young (1773–1829) (in 1801) and Augustin Jean Fresnel (1788–1827) who developed mathematical theory of diffraction in 1818 (+ of double refraction in biaxial crystals)
   └ light is a transverse wave (1821)

Prediction of 'bright spot' by Poisson in 1818. (defect of theory, prize competition examiners) — demonstrated by Fresnel — prime example of a novel prediction.

└→ Elastic-solid theories of the luminiferous aether

2. Faraday and electromagnetism

Michael Faraday (1791–1867) Assistant to Davy at the R.I. succeeded him as director.

Hans Christian Oersted (1777–1851) discovered the magnetic effect of a current in 1820, lead to Naturphilosophie

└→ Electric motor {, Faraday (1821) ~~Arago~~

Reverse effect of electromagnetic induction discovered by Faraday in 1831 (change in magnetic field is required)

Faraday introduced theory of electrotonic state (stress thro' a system of particles) → Force Atoms → lines of as bar theory magnetic Force

1834 Discovered laws of electrolysis

1837 - 1838 Discovered specific inductive capacity effect of dielectric

1845 Discovered Faraday effect ~~Rotation~~ optical rotation induced by a magnetic field (suggested to Faraday by Kelvin)

~~1846~~ 1845 Discovered diamagnetism

repulsion of Bi by a magnet ← (although it had been discovered by Brugmans in 1778)

– theory of conductibility of magnetic lines of force (reverses Weber's reverse polarity theory) i.e. polarity theory of electrotonic state now quite replaced by lines of force idea.

cp III, pp. 200 et seq.

Faraday's work on gravitation & conversion of forces was his last serious work.)

Faraday influenced by Coleridge – letter to Boscovitch.

a) Did not believe in atoms of matter – only centres of force. (Speculations on ...)

b) Force exists as 'lines of force' – element of reality for Faraday

c) No action at a distance, eventual effect of the medium, ; later force field

d) did not believe in an aether

N.B. It was Heaviside who insisted on $\underline{E}$, $\underline{H}$, not $\underline{A}$ as the 'reality' of the field.

After 1865 whole of physics based on 2 sets of equations:

Matter	aether models	Field
Newton		Maxwell
mechanics		E a field of ether
hydrodynamics		
heat		

aether models seek to reduce field to mechanical action i.e. reduce field to matter

cf Einstein's unified theory, matter reduced to field

Faraday was no mathematician.
, anticipated e.g. theory of light
in his 'Thoughts on Ray Vibrations'

Faraday's views contrast with work of Continental (French) Action at a distance School represented most prominently by André Marie Ampère (1775-1836) and Wilhelm Weber (1804-1891) {and also Helmholtz}.

Faraday's ideas given a mathematical model by

Kelvin (in 1845))
and then taken up by

Maxwell in 3 papers.

1856 - On Faraday's Lines of Force — fluid model.

1861-1862 On Physical Lines of Force — vortex model — molecular
electrotonic state = Vector potential correctly H as well

1865 On a Dynamical Theory of the Electromagnetic Field (dispenses with models)

1) Energy located in the field
of Π oscillations $E_e + E_h = \text{const}$
E_e, E_h of Poynting Vector (1884)

2) Concept of the luminiferous aether
— continuous around stars & conductors — even in a vacuum

↳ e.m. theory of light (   )

E.M. Waves detected by
Heinrich Rudolf Herz (1857–1894) in 1886–1888
cf Herz: Electric Waves.

2nd half of 19th century elaborate aether models + vortex theory of atoms (Kelvin, J.J. Thomson (not Son))
↳ reduces all matter to aether

Attempts to detect motion relative to the aether:

Aether-dragging Fresnel – verified by Fizeau and ~~Foucault~~ Airy (water filled telescope no effect on aberration)
(1851) (1871)

Stationary aether + electron theory of H.A. Lorentz (1853–1928)

Michelson – Morley Experiment (1887)
↳ Lorentz-Fitzgerald Contraction (1892)
↳ Special Relativity (1905)

But note Albert Einstein (1879–1955) did not abolish the aether – of 'substantival' idea of space-time in G.R. Matter is defined in terms of space-time (singularities?) also e.m. fields as additional geometrical structures (H. Weyl 1918).

↳ Geometrization of physics (Geometrodynamics)

But relativity denies instantaneous action at a distance – all effects transmitted with finite speed (either as particles or as disturbance of the field)

James Clerk Maxwell (1831 – 1879)
1st mathematical paper at age of 14.
b. Edinburgh 1850 went up to Cambridge
2nd Wrangler, Joint 1st first Smith's Prizeman
(with E. J. Routh). Taught at Aberdeen,
King's College London. Appointed 1st Cavendish
Professor at Cambridge in 1871.

Main Contributions
1.) Electromagnetic theory
2.) K. T. Gases
3.) Theory of Colour vision
4.) Theory Saturn's rings
5.) thermodynamics
6.) Geometrical optics. etc.

Joint ed. with T. H. Huxley of 9th ed.
of Enc. Britannica.

Ryd. Books 1870 Theory of Heat (thermodynamic relations & Maxwell's demon)
1873 Treatise of Electricity & Magnetism
1881 (Posthumous) Elementary Treatise on Electricity.
1879 The Unpublished Electrical Writings of Hon.
Henry Cavendish

Life of Maxwell by L. Campbell & W. Garnett
(1882)

Recent life by C.W.F. Everitt
(who also wrote entry in Dic. Sci. Biog.)